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13. ABSTRACT (Maximum 200 words)

The report w as developed under SBIR contract for topic N04-124 (Joining methodologies for Titanium alloys)This investigation has established the hybrid plasma/GMAW (Super-MIG)w eld process as a viable process for w elding Titanium. Compared to traditional GMAW w elding, this hybrid process dramatically increases w elding speed and penetration (both mor than double) w hile producing w eld joints w ith minimal spatter and w ith superior profile and mechanical properties. Weld joints observed had a high degree of visual and metallurgical quality, free of porosity, cracks and contamination. The Super-MIG process demonstrated capability for various types of automated w elding of Titanium structures.

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Update

1. Introduction: Joining Methodology for Titanium Alloys

The SuperMIG™ technology increases productivity by combining the plasma and MIG welding processes and providing the benefits offered by both methods. The key features of the system that allow the integration of two welding processes are:

- The welding head
- The control system.

The welding head uniquely integrates the consumable MIG electrode and the non-consumable plasma electrode so that the axes of both the consumable electrode (MIG-GMAW) and the non-consumable electrode (plasma arc) have an acute angle facing the work-piece.

The net result is that the SuperMIG™ process combines the major advantages of a plasma arc for deep penetration with the high arc efficiency and metal transfer of a GMAW.

The interaction between the plasma arc flow and the MIG arc promotes wire heating and current transfer at the anode spot (at the end of the GMAW filler wire) where the molten weld metal droplets form and subsequently detach. The resultant magnetic force F, shown_in the figure below (Fig.1), occurs as a result of the interaction of the electric currents passing through the two electrodes.

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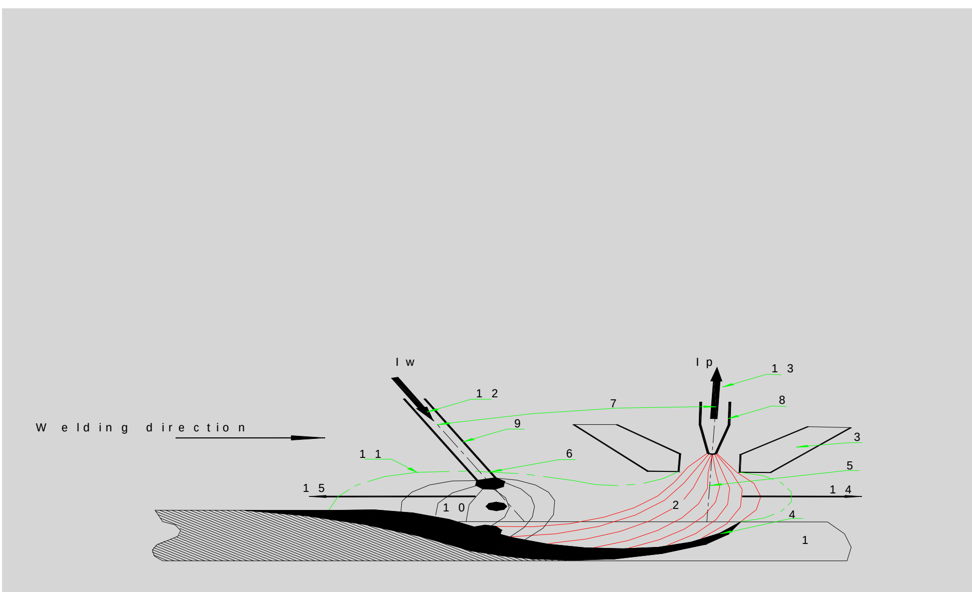

Fig. 1 Process description

1 – Work-piece; 2 – Plasma jet; 3 – Plasma nozzle; 4 – Melting metal;

5 – Plasma arc electrode axis; 6 – Wire axis; 7 – Angle between electrode’s axes;

8 - Tungsten electrode; 9 – Consumable electrode (wire); 10 – MIG arc; 11 – Low temperature plasma; 12 – Wire current Iw direction; 13 – Plasma current Ip direction;

14 – Magnetic forces **F** applied to plasma arc**;** 15 – Magnetic forces **F** applied to MIG arc.

The SuperMIG™ process uses a negative plasma arc electrode and a positive MIG-GMAW electrode to achieve maximum processing speed and to operate in the spray transfer mode). The magnetic force F causes deflection of the plasma arc towards the front of the welding pool, thus compensating for the plasma arc's natural tendency to trail behind the torch axis during high speed welding. The resultant effect is a substantial increase in the plasma arc rigidity and stability leading to a substantial increase of penetration depth and welding speed.

Integral to the SuperMIG™ technology is a patented SoftStart™ arc ignition technology to eliminate the effect of the electromagnetic interference during the establishment of the pilot arc, which also substantially increases the non-consumable plasma electrode lifetime.

2. PROJECT MAIN OBJECTIVES

- Determine the feasibility of the hybrid SuperMIG™ welding process (Plasma/GMAW) to deposit titanium weld metal with good mechanical and chemical properties compared to a baseline GMAW weldment;

- Identify fabrication benefits of the SuperMIG™ welding process in terms of productivity, joint design, shielding requirements, and overall quality:

- Optimum major welding parameters;
- Weld profile and penetration;
- Productivity increase in comparison to GMAW;
- Design of optimized trail gas shield;
- Determine mechanical properties and metallurgical integrity of the SuperMIG™ welds;

3. Assessment of success

The demonstration of and hence viability of the hybrid SuperMIG™ process has been determined by assessment of the data collected above against existing data for stable but slow GTAW and the best to date and still impractical and unstable pulse GMAW deposits.{Where is from?}

The key criteria used were the following:

- The weld bead profile: penetration,
- Droplet formation and detachment.
- The processing speed;
- The mechanical properties and metallurgical integrity of deposited weld metal.
- The color of the deposited weld metal

4. PROCEDURE

4.1. Welding Cell Set-up (Fig.2). Project was performed using the following equipment and working layout:

1. Robot: ABB IRB 2400/16
2. Welding Table;
3. Tooling/Clamping as for typical standard MIG welding procedure
4. Fully integrated S-MIG™ welding system consists on the following items:

   - integrated KEMPPI MIG PS3500 and Stick Master 3500 power supplies with an embedded controller UNITRONIX;
   - KEMPPI FU-11 Wire feeding mechanism
   - S-MIG™ welding torch (Fig. 2) connected at the end of the Robot arm with protective trail gas shield;

5. Data Acquisition System based on portable USB 9215 DAQ .
6. System integration of above components to allow for fully automatic operation.

Fig. 2. S-MIG™ Integrated Welding Cell

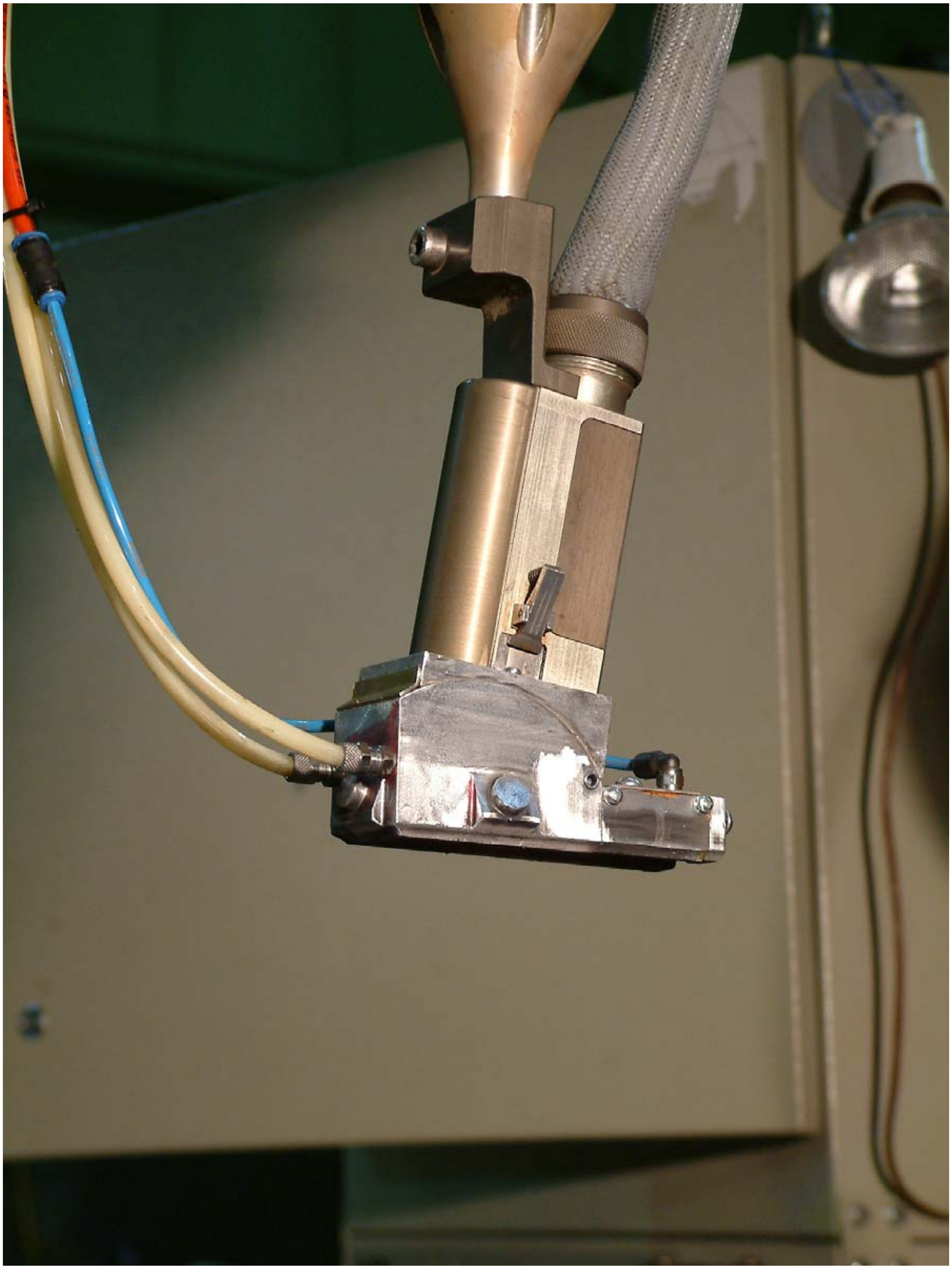

Fig. 3. S-MIG™ Processing Torch with Trailing Shield

4.2. Materials and surface preparations.

The following materials were utilized:

- Pure Titanium GR 2Ti 1/4 " THK
- ER Ti-1 .045"Filler Wire

Surface of all coupons were alkaline cleaned and wire brushed before welding.

4.3. Data collection.

Data Acquisition System (see Fig. 4) monitored electrical parameters of welding such Plasma Arc Current, MIG Voltage and MIG Current.

Fig.4 Data Acquisition System based on USB 9215 DAQ manufactured by National Instruments.

5. RESULTS

5.1. Further Processing Head Modification.

One of the existing problems with the GMAW process in addition to limited processing speeds and shallow penetration is severe undercutting of the Titanium material.

To reduce this problem, we incorporated a major modification in our processing torch. We found that by positioning within the processing torch body a device that introduced a magnetic field influence on the melting pool during the welding we were able to greatly reduce the effect of undercutting during the high-speed welding (Fig.5). This torch modification produces an interaction between the current carrying molten metal and the magnetic field created by magnetic poles located within the processing head body.

This torch modification has enhanced our ability to produce the perfectly symmetrical welds without undercuts (Fig 6).

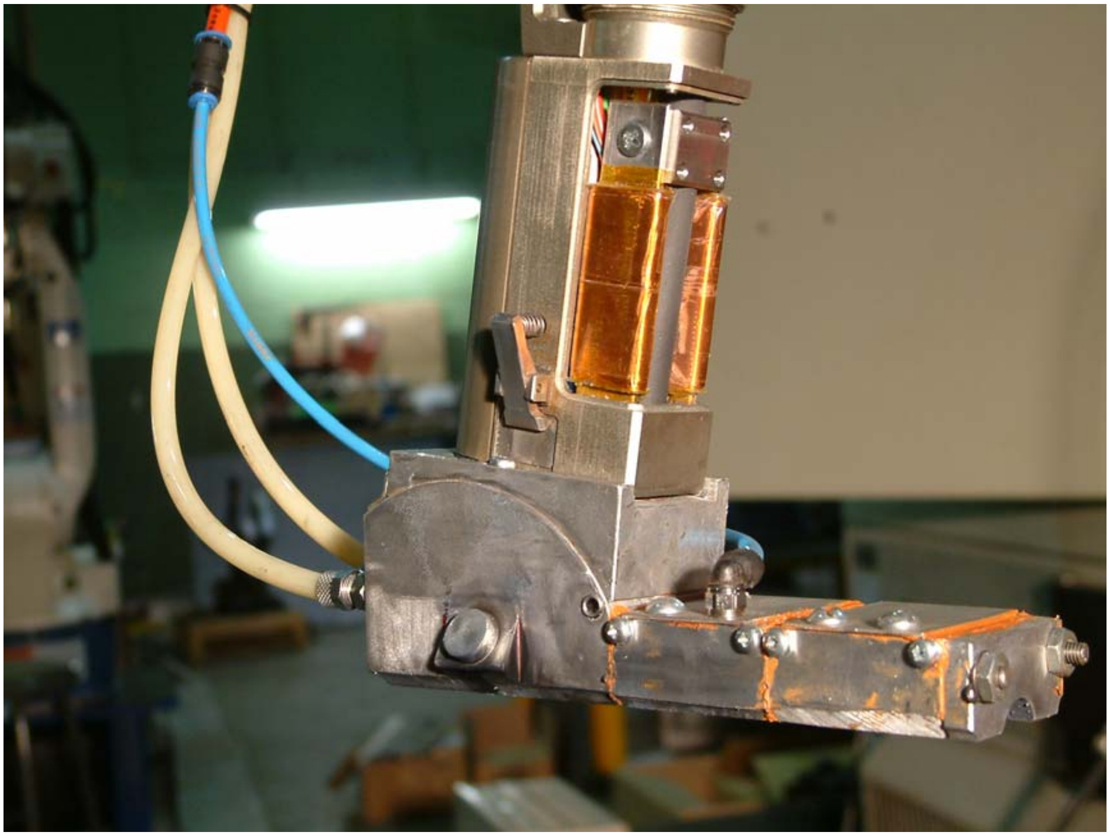

Fig.5 Magnetic device placed in SMIG Torch Body. (Copper attachment)

Fig.6. Symmetrical butt weld produced by torch with magnetic device.

5.2. Protective trail gas shields

The so-called modular flexible design of the gas shield has allowed us to adjust the processing speed assuring very high metallurgical integrity and mechanical properties of the final welds. (Fig. 7a). Also, it has shown very good adoption to the automated applications. Fig.7b shows attachable module.
In addition, the major modification done had allowed following:

- Prevent the atmospheric contamination of deposited weld metal until it cools below 450°C.
- Added a supplementary gas shield to the weld head to address the “venturi” entrainment effect associated with high primary plasma gas flow rates.

5.3. Parameter optimization

Parameters optimization has been done based on the combination of the visual examination, cross-sectioning of the welds and stability of current voltage. (Fig.8 Fig.9).

The goal was to obtain both shiny, without contamination weld; and maximum penetration weld free of porosity, cracks, and holes.

Also, optimum welding speed corresponding with the maximum penetration was our goal.

The Table 1 summaries the optimum set of welding parameters for our SuperMIG™ welding process:

Table 1.

AIT/Optimum welding conditions						
Parameters	**Plasma current**	**Wire voltage**	**Wire speed**	**Speed**	**Plasma Gas (Argon)**	**Shield Gas**
Optimum Speed	220A	32V	708ipm	48ipm	12cfh	40cfh (25%Ar75%He)
Optimum Penetration depth	240A	33V	780ipm	35ipm	12cfh	40cfh (75%Ar25%He)
Deposition rate	240A	33V	800ipm	35ipm	12cfh	40cfh (25%Ar75%He

Deposition rate is limited by wire feeder capability and wire diameter. It may be increased by using bigger wire (.062” or 1/16”).

5.4. Quantification of the weld bead profile and degree of penetration

The significant number of weld beads on plate under steady state conditions has been examined against of the benchmark MIG welding of the same titanium alloys.

It has been clearly shown that the SuperMIG™ welding technology has exceeded the traditional MIG welding technology both in terms of penetration (More then 2 times); and processing speed (More then 2 times).(Fig.10,Fig 11).

As it has been shown the weld profile exhibits very much symmetrical shape, which generally is preferable to obtain high mechanical properties of the final weld.

5.5. Determination of productivity.

The productivity increase has been determined based on the following major parameters:

- The weld deposition rate increase in comparison to the MIG alone: more then …. times
- A reduction in the number of man-hours required to remove weld spatter through improved stability; we have set-up the process which
- Improvements in inter-run weld bead profile
- The capability of the current system to deposit weld metal productively in both groove and fillet welds,
- The deposition rate quantified against the relationship between the plasma and GMAW process powers.

5.6. Mechanical testing of butt welds.

The final verification of the "hybrid" **SuperMIG™** process has been provided by making butt welds. It was the subject of the metallurgical examination together with mechanical testing of the deposited weld metal.

Altogether 10 specimens have been submitted to the Climax research for the investigation and we have been waiting to the final data to be submitted.

6. Conclusions.

1. The SuperMIG™ process has shown a superior performance in comparison to the GMAW in terms of penetration (more then 2 times) and processing speed (also, more then 2 times)
2. The SuperMIG™ process also has shown a very consistent weld with high visual quality and metallurgical integrity;
3. Welding process with the SuperMIG™ facilitates with minimum and almost no spatters surface;
4. Specifically designed shielding trial assures high visual quality; extended flexibility; and overall weld quality;
5. The SuperMIG™ process also demonstrates readiness for any type of automated applications
6. First presented results generated high interest among the industry and have lead to the potential partnership with the General Dynamic Land System and Titanium fabrication contractor for the Second Phase of the Project.

*See attached photos Pages (14-17)

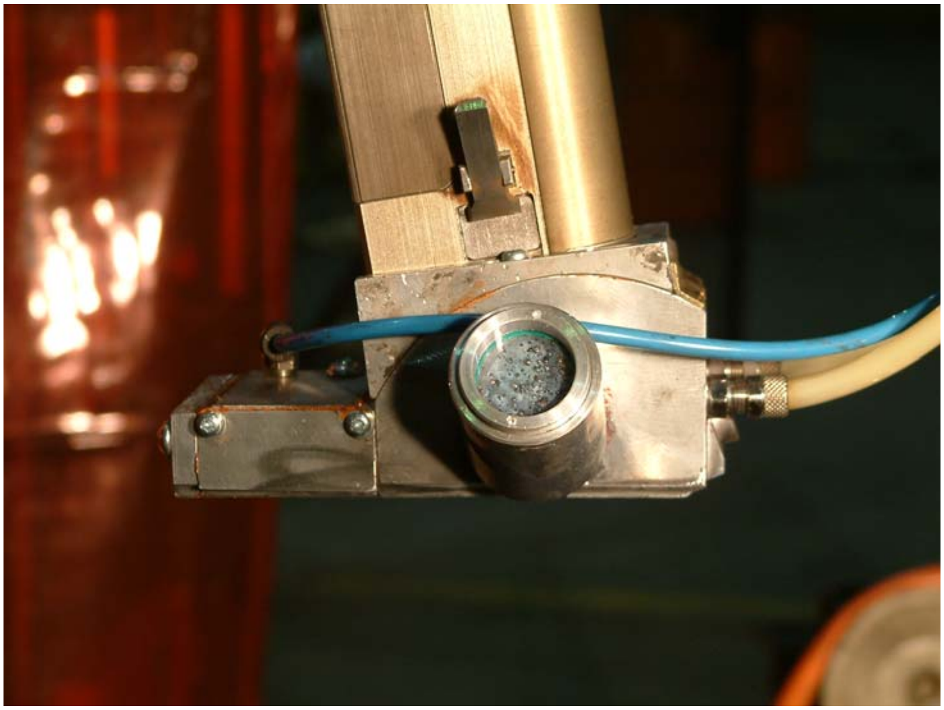

Fig.7 a Protective trail shield with one detachable module and window placed on Processing Torch Body. AIT Photo

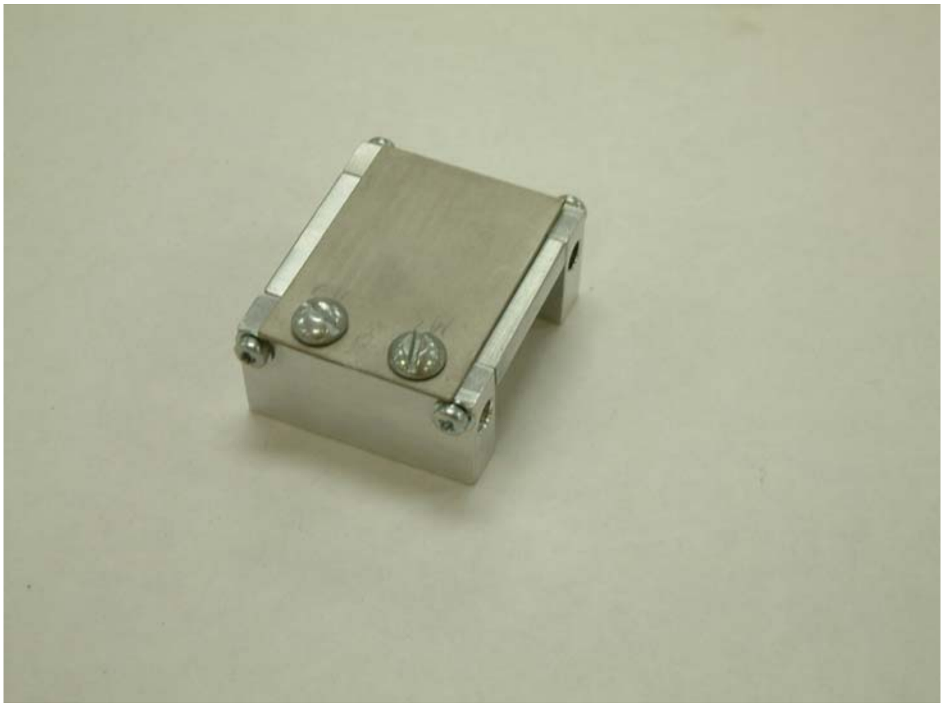

Fig.7b. Protective trail shield module; Up to 6 modules can be detached to protective shield. (AIT Photo)

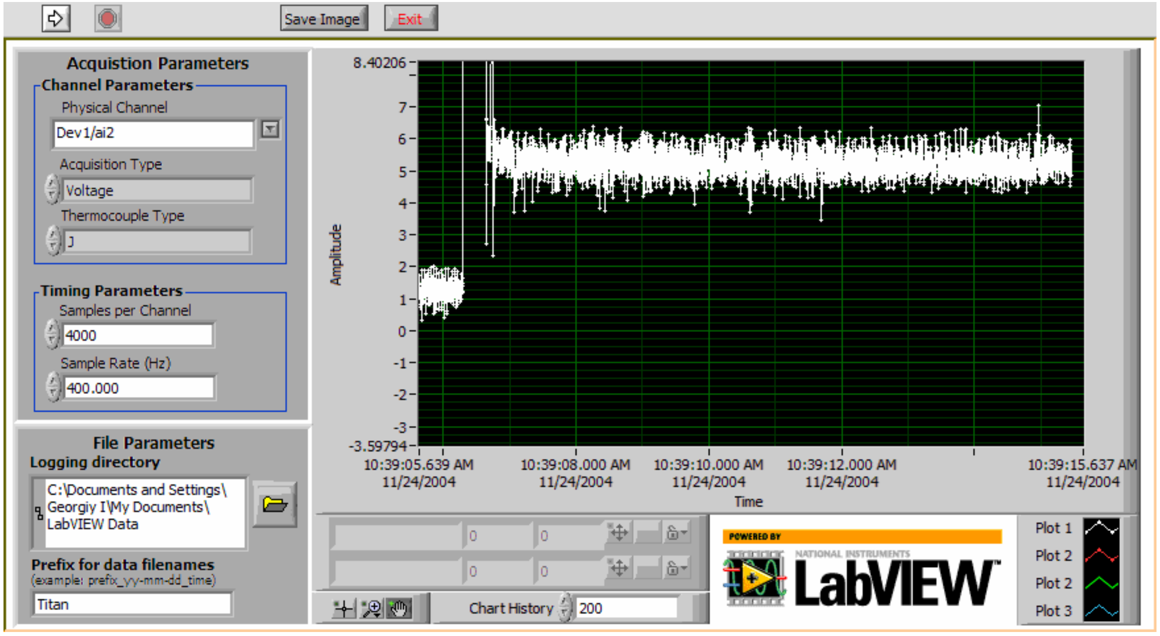

Fig.8 MIG Voltage data chart during welding.

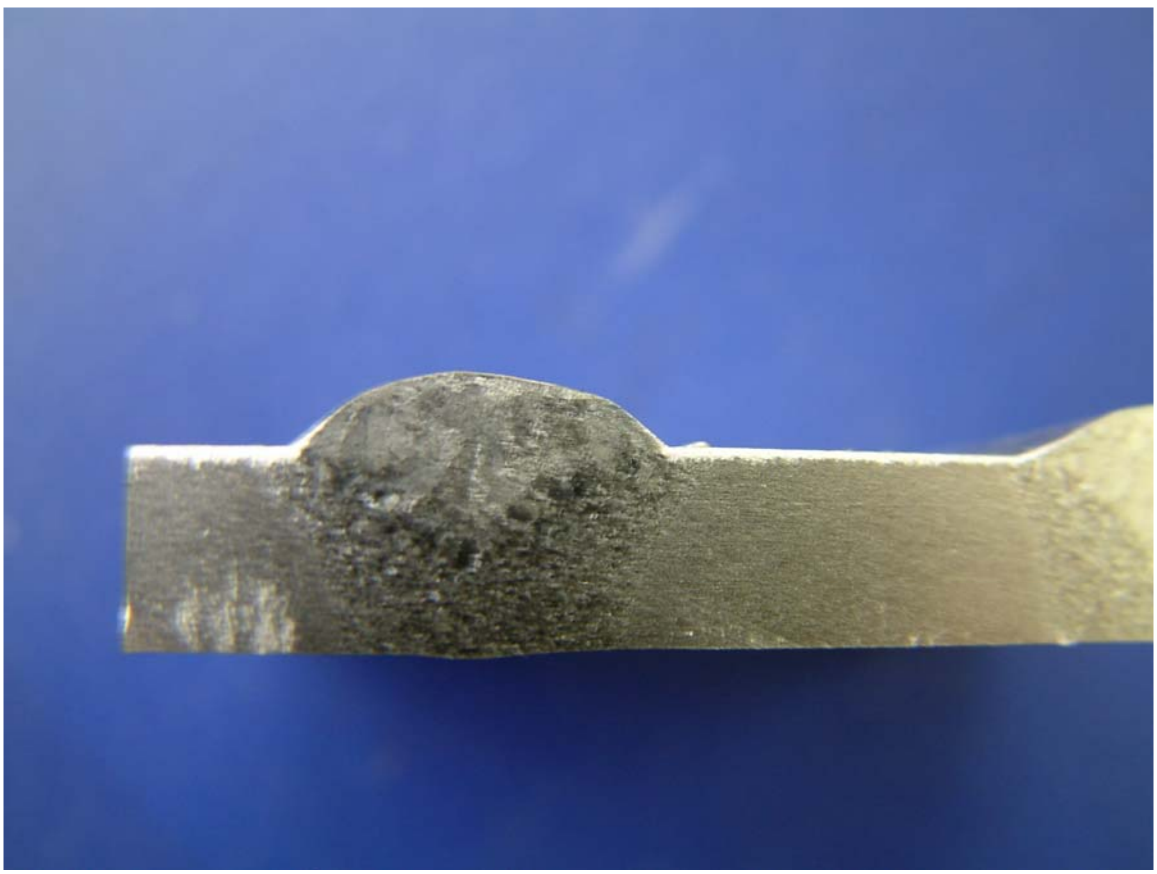

Fig.9 Cross-section of Bead on Plate.

Fig. 10 Butt weld cross-section: Welding Speed - 30ipm, Wire speed 780ipm.

Fig. 11 SMIG-MIG comparison; S-MIG weld (left) in 1.8-2 times deeper than MIG weld (right), Welding speed, wire speed and wire voltage are same for both welds.